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Art. II.—*On the Occurrence of Quartz-Tourmaline Nodules in the Granite of Clear Creek, near Everton.*

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Introduction.

The curious development of quartz-tourmaline nodules in the granite of Clear Creek, near Everton, was first recognized by Mr. W. Baragwanath, Director of the Geological Survey of Victoria, in 1932. Phenomena of this type are rare, although they have been recorded from several localities in widely separated parts of the world. Quartz-tourmaline nodules have long been known to occur in the granites of the Tasmanian tin fields of Stanley River (1), and Heemskirk (2), (3), where they are especially well developed. Similar nodules have also been described from an aplitic phase of the Cape Willoughby granite at Kangaroo Island, South Australia (4), from the Dartmoor granite of Devon (5), from aplites in Montana (6), (7), and recently, from the porphyry intrusive stock of the Llallagua-Uncia tin field of Bolivia (8).

At my request, Mr. J. C. Grieve, Inspector of Mines at Wangaratta, revisited the area, and made a collection of the nodules and the granite. The specimens, together with brief notes on the nature of the occurrence were forwarded to me at Imperial College, but their examination was delayed. The field description of the occurrence, in the following notes, is based entirely upon Mr. Grieve's information.

Locality.

Clear Creek is a small watercourse draining a granitic catchment of about 25 square miles in the Parish of Byawatha, County of Bogong. As shown in the accompanying sketch map (Fig. 1), it is a tributary of Reedy Creek, which flows into the Ovens River, near Wangaratta.

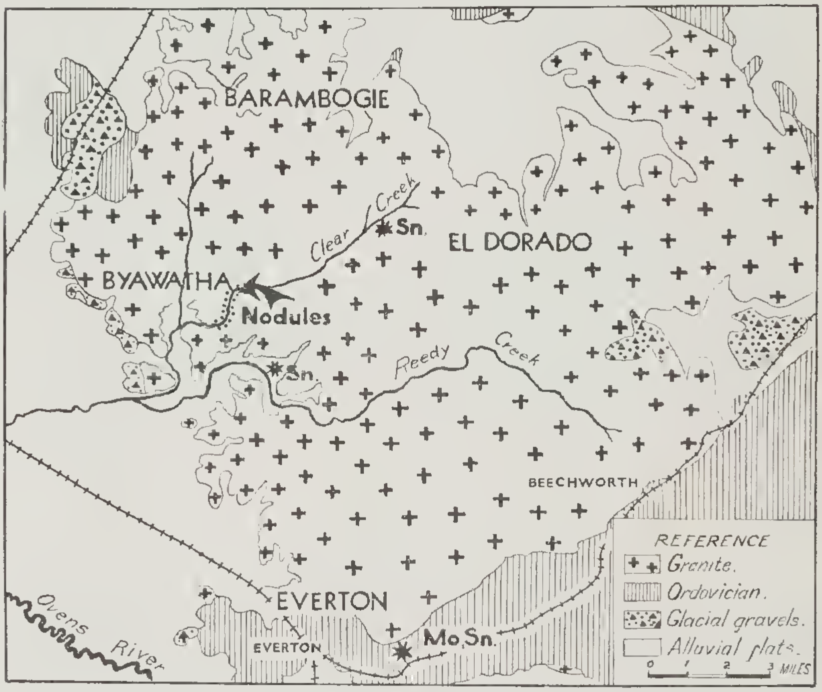

Fig. 1.

Over the lower two miles of its course, Clear Creek flows through a narrow gorge, and it is in this gorge that the quartz-tourmaline nodules are exposed. The stream drops about 250 feet in this section of its course, chiefly in three separate and abrupt falls. Downstream, towards the Ovens Valley, the bedrock is covered to a depth of 30 feet or more by alluvium, and the junction of the granite with the Ordovician sediments cannot be observed. Upstream, for about eight miles, the stream has a slight gradient over a granitic plateau.

The Granite.

The granite in which the quartz-tourmaline nodules occur is of variable texture, grading rapidly from a fine-grained granite into aplite. It is composed essentially of quartz and orthoclase, and a lesser amount of oligoclase. Biotite is the only ferro-magnesian mineral, and is not abundant. The quartz forms patches about 1 cm. across, which are generally composed of several interlocking, allotriomorphic grains. The orthoclase is frequently sericitized, and forms large crystals up to 1 cm. in length, or it may occur as smaller interlocked grains. It tends to predominate over the quartz. The biotite plates are somewhat chloritized; and the accessory minerals are zircon and apatite.

The proportion of the minerals is much the same in the aplitic phases, but the grain size is considerably finer.

The granite closely associated with the nodules appears to be generally finer-grained than the granite which constitutes the plateau. This association of quartz-tourmaline nodules with a fine-grained phase of the granite in which it occurs is a point in common with most of the known occurrences of such nodules.

The Quartz-Tourmaline Nodules.

Distribution.

The quartz-tourmaline nodules persist throughout the two miles of gorge tract of Clear Creek, being especially well exposed in the creek bed. The nodules are not evident in the granite at the sides of the gorge, but Mr. Grieve found them in several boulders which were not *in situ*. Above the gorge section, and in the coarser granite of the plateau, the nodules do not appear to be developed. Much of the granite in these parts is hidden by shallow gravels, but, despite this, Mr. Grieve concluded that the development of the nodules was more marked where the creek channel had cut deepest into the granite.

The distribution along the gorge is variable. In places the nodules diminish in number, and at others they become much smaller than usual—about half an inch in diameter. They constitute about 1 per cent. of the granite in this section, although there are limited areas in which they are more plentiful. At the lowermost of the three falls there is an aplitic dyke, striking north-south with a dip to the east, and small quartz-tourmaline nodules, about half an inch across are developed in the dyke.

The nodules are scattered through the granite, and do not appear to have formed along any defined lines or zones; nor do the longer axes of adjacent nodules show any parallel orientation.

Description.

The nodules are ellipsoidal in shape, and average about 2 to 3½ inches in their longest diameter. They vary in size from place to place, but, in any one small area, are all more or less uniform. They may decrease to half size in a distance of about 100 yards, and then show an increase in another 100 yards. The largest nodule observed was 5½ inches across, and the smallest about ½ an inch across.

Where the weathering has been solely atmospheric, as on the boulders on the side of the gorge, the nodules, on account of their greater resistance, form ellipsoidal protuberances, "like warts", on the granite. In the creek bed, however, where they have suffered attrition, they do not protrude, but form elliptical dark patches.

The nodules consist of tourmaline, quartz, a minor amount of orthoclase, often sericitized or kaolinized, and a little muscovite. The tourmaline frequently forms clusters of acicular needles which radiate outwards from the central part of the nodule. It is interstitial to the quartz crystals, and, especially towards the periphery, can be observed replacing the original orthoclase *in situ.* The tourmaline is mostly blue in colour, sometimes greenish-blue, but it grades into small areas of brown tourmaline. The brown tourmaline is probably derived from the original biotite of the granite (9), while the blue tourmaline obviously results from the alteration of the orthoclase. The tourmalinization commences along the cleavages of the felspar (Fig. 2, A), and spreads outwards, so that, in the closing stages of the alteration, the felspar is represented only by parallel inclusions of felspar within the tourmaline (Fig. 2, B). The change is most complete in the central part of the nodules, and towards the peripheries there is an increasing amount of unaltered felspar. The edges of the nodules are irregular, but are sharply defined, indicating the exhaustion of a limited supply of boron and other mineralizers.

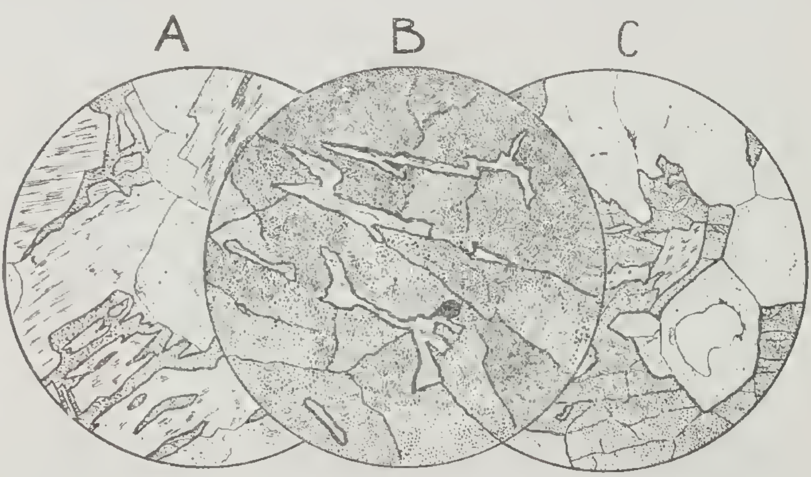

Fig. 2.

The larger areas of quartz consist of interlocking allotriomorphic grains, similar to those in the adjacent, unaltered granite; but the quartz enclosed in, or in contact with, the tourmaline, is often idiomorphic. In some instances these idiomorphic quartz crystals are observed to have an allotriomorphic core, on which later deposition of quartz has built an idiomorphic rim of similar optical orientation (Fig. 2, C). There is also a certain amount of granular, interstitial quartz. This and the secondary rims are probably the residual product of the reaction:—

$$\text{Orthoclase} + \text{boron} \rightarrow \text{tourmaline} + \text{quartz.}$$

Usually the quartz and tourmaline are in about equal proportions, but in one specimen the tourmaline almost excludes the quartz, and forms striated prismatic crystals, nearly 2 cms. long, with minute vughs between them.

Zircon is the only other mineral which has been observed in thin section. Any apatite in the original granite has disappeared during the formation of the tourmaline.

Cassiterite is frequently present in the Tasmanian nodules, but has not been observed in those from Clear Creek. In this they resemble the Cape Willoughby, Dartmoor, and Llallagua-Uncia nodules.

Cassiterite occurs, however, in the granite, although no tin lodes are known to exist. A considerable amount of stream tin has been mined along the upper section of Clear Creek (Fig. 1), where it is associated with a tourmaline sand, and an occasional colour of gold. Mr. Grieve considers it probable that the stream tin is derived from the breaking up of numerous minute veinlets of stanniferous quartz traversing the granite. Cassiterite and molybdenite are found in the Ordovician sediments at the southern contact of the granite, and have been mined.

Origin of the Nodules.

In common with the similar nodules from elsewhere, these quartz-tourmaline nodules occur in a more fine grained granite than that making up the mass of the stock in which they occur; the tourmaline is mostly the blue aluminous variety, and has replaced orthoclase felspar *in situ;* and the development of the nodules appears to post-date the intrusion of aplite material into the granite.

The earlier writers (1, 2, 3, 6, 7), considered such nodules to represent magmatic segregations, although Barrell (6) did not entirely exclude the possibility of a pneumatolytic origin for them. The later writers (4, 5, 8), consider them to be of pneumatolytic origin, on account of the *in situ* replacement of the felspars. The most complete picture of their origin is given by Tilley (4). He pictures a reduction of pressure accompanying the intrusion of aplite into the semi-crystalline granitic magma.

This reduction of pressure caused the development of bubbles of mineralizers, which rose in the viscous magma until they reached the crystal mesh of quartz and felspar, when they attached themselves to these crystals. With further cooling the mineralizers became active, and the boron attacked the felspars and biotite, converting them into aluminous tourmaline, at the same time depositing the excess silica as secondary quartz. Brammall (5) also suggests that such nodules have developed by an "auto-pneumatolysis" of this type, or that such bubbles have attacked small basic segregations or xenoliths of biotite and plagioclase. Tilley's explanation of the Clear Creek nodules seems the more probable, since there is no evidence of the former existence of such xenoliths.

Quantity of Boron.

The average B_2O_3 content of tourmaline is approximately 10 per cent. Therefore, since the proportion of quartz and tourmaline in the nodules is about equal, and the nodules constitute about 1 per cent. of the granite in which they occur, the B_2O_3 constitutes about 0.05 per cent. of the granite, i.e., 5 tons of B_2O_3 or 1.5 tons of Boron per 100,000 tons of granite. No figures appear to be available which would permit of a comparison with the average B_2O_3 content of granites.

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